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Overview of a Welding Development Program for a Ni-Cr-Mo-Gd Alloy

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W. L. Hurt
D. E. Clark
R. E. Mizia
C. V. Robino

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Authors
W.L. Hurt, D.E. Clark, R. E. Mizia,
Idaho National Laboratory
Idaho Falls, ID 83415-3710
william.hurt@inl.gov
denis.clark@inl.gov
ronald.mizia@inl.gov

C. V. Robino
Sandia National Laboratories
Albuquerque, NM. 87185-0889
cvrobin@sandia.gov

INTRODUCTION

The National Spent Nuclear Fuel Program (NSNFP), located at the Idaho National Laboratory, coordinates and integrates management and disposal of U.S. Department of Energy-owned spent nuclear fuel. These management functions include using the DOE standardized canister for packaging, storage, treatment, transport, and long-term disposal in the Yucca Mountain Repository. Nuclear criticality must be prevented in the postulated event where a waste package is breached and water (neutron moderator) is introduced into the waste package. Criticality control will be implemented by using a new, weldable, corrosion-resistant, neutron-absorbing material to fabricate the welded structural inserts (fuel baskets) that will be placed in the standardized canister.

The new alloy is based on the Ni-Cr-Mo alloy system with a gadolinium addition. Gadolinium was chosen as the neutron absorption alloying element because of its high thermal neutron absorption cross section.

This paper describes a weld development program to qualify this new material for American Society of Mechanical Engineers (ASME) welding procedures, develop data to extend the present ASME Code Case (unwelded) for welded construction, and understand the weldability and microstructural factors inherent to this alloy.

Alloy Background

The alloy system under investigation here has been specified as UNS (unified numbering system) N06464 under ASTM International Standard B932-04, and has the following typical composition (weight percent): Cr-16.8, Mo-14.4, Gd-2, Ni-Balance.

A typical microstructure for the Ni-Cr-Mo-Gd alloy is shown in Fig.1. The microstructure consists of a Ni-Cr-Mo austenitic matrix (darker structure) and a dispersed secondary phase (lighter structure) with a crystal structure based on the Ni_5Gd gadolinide. (1) This hard second phase is generally found at the austenite grain boundaries. The size, shape, and distribution of the secondary phase evolves from its initial solidification morphology in the interdendritic regions of the as-cast ingot through hot rolling and heat treatment to the wrought structure illustrated here. Gadolinium has extremely limited solubility in the nickel austenite matrix.

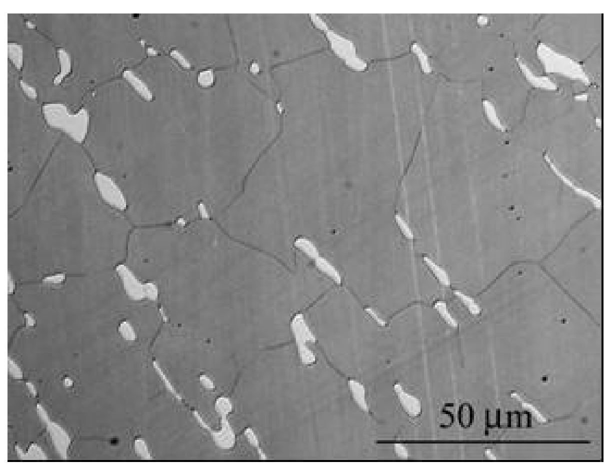

Figure 1 Ni-Cr-Mo-Gd wrought microstructure

DESCRIPTION OF WORK

Weldability

Weld microstructure and parameter effects

Welding involves the production of an as-solidified microstructure and a heat-affected zone (HAZ) in the unmelted base material as shown in Figure 2. The scale and microstructure is determined by the welding process and parameters. The experimental work described here involves gas tungsten-arc welding at various parameters to assess the effect of these variables on weld and HAZ microstructure refinement and properties.

Dilution

Studies are being performed with a non-Gd-bearing filler metal to derive the optimal dilution for mechanical properties and cracking resistance. Dilution can be adjusted by changing welding parameters.

Welding Process Development

This requires the development of both welding procedures and post weld heat treatment (PWHT) to improve the mechanical properties of the weld. The steps involved are:

- Identify welding procedures that improve as-welded properties
- Quantify PWHT time, temperature and quenching procedures
- Quantify the relationships between welding procedures and PWHT procedures

Weld Procedure Qualification

This portion of the development is intended to provide a demonstration that welds can be suitably qualified to ASME B&PV, Section IX rules.

Development of an ASME Code Case for Welded Construction

This material has been approved for ASME B&PV Code, Section III, as Code Case N-728.(2) This paper describes the ongoing work required to generate information to support a welded code case submittal.

Code cases are established by developing appropriate processing conditions and performing tensile, bend, and Charpy impact energy absorption tests. These were done for test heats in the present work.

RESULTS

Weldability

The welding process involves melting and solidification with a resultant redistribution of the second phases. Figure 2(a) shows the partially melted zone of the weld heat-affected zone (HAZ) and shows that the gadolinide in the HAZ is distributed as an interdendritic eutectic-like constituent and are interconnected near the fusion line of the weld. This interconnectivity of the gadolinide has a strong negative influence on the mechanical properties of the HAZ.

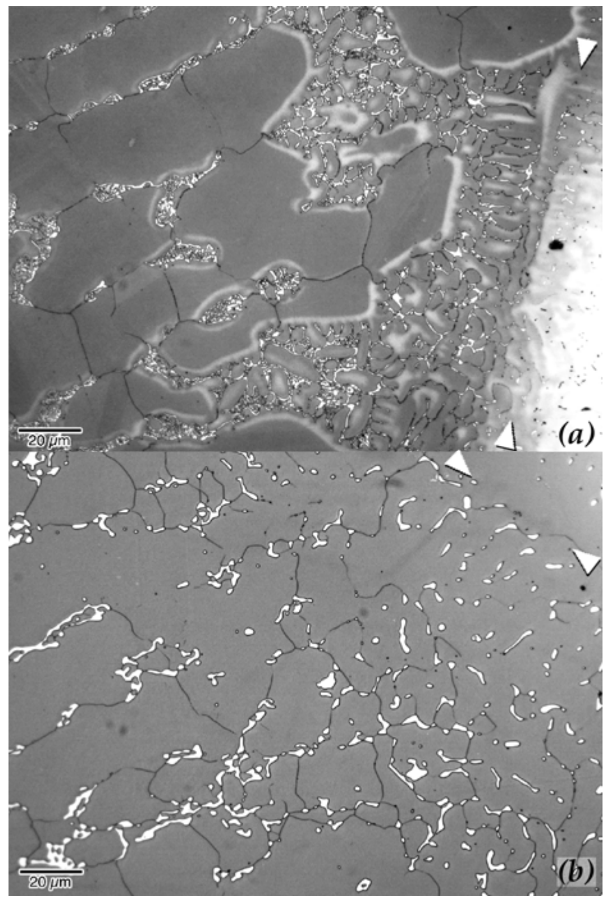

Figure 2. (a) HAZ in Ni-Cr-Mo-Gd weldment; (b) HAZ in Ni-Cr-Mo-Gd weldment following PWHT at 1168°C for 8 hr. Arrows indicate approximate weld fusion lines.

The properties of the welded materials were improved by post-weld heat treatments at temperatures of 1100-1200°C. Figure 2(b) shows that the PWHT spheroidizes the gadolinide and restores the HAZ microstructure to one similar to the base metal. Such heat treatments may be undesirable for large fabricated parts such as the fuel baskets owing to the difficulty of heat treating these structures.

Code case status

The fabrication of the welded test specimens that will be used for the generation of mechanical properties data for the extension of ASME Code Case N-728 will begin after the welding process and welding procedure development. The required measurements include mechanical properties (ultimate strength, yield strength, total elongation, reduction of area), Charpy impact tests (impact energy, lateral expansion), and fracture toughness for the as-welded and/or PWHT conditions.

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